LA-UR -85-3005

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CONF-8509153--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--85-3005

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TITLE PREDICTING FUEL PERFORMANCE FOR SP-100 CONDITIONS

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SUBMITTED TO To be presented at the Second SP-100 Program Integration Meeting on September 17-19, 1985, in Denver, Colorado.

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PREDICTING FUEL PERFORMANCE FOR SP-100 CONDITIONS

by

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INTRODUCTION

This paper reports on our methods for analyzing fuel designs proposed for the thermionic and thermoelectric concepts for SP-100 application.

THERMIONIC CONCEPT

The proposed fuel design for the thermionic concept consisted of fully-enriched oxide fuel clad in chemical vapor deposition (CVD) tungsten, which also served as the emitter for the thermionic fuel element (TFE). The fuel density was 95% of theoretical with the linear heat rate flattened radially by removing fuel from the center of the fuel pellet. The fuel inner diameter varied from ~0.45 in. at the core center to zero at the edge of the core. The as-fabricated gap between fuel and emitter was 10 mils radial. The emitter thickness was 80 mils, and the outer diameter was 1.099 in.

We decided to use the LIFE-4[1] code for evaluation of this concept after extensive review of the code and development of a procedure that corrects certain deficiencies we noted in analysis of several tests. The procedure also simulates a phenomenon that is not modeled in LIFE but is believed to occur in the thermionic design. That phenomenon is the vapor deposition of fuel on the inner surfaces of cladding in those designs either sealed or operated in a vacuum. Predicted cladding deformations are compared in Fig. 1 with measured deformations for several SP-100 type tests.[2-5] Predicted fission gas release and volume swelling are compared in Fig. 2 with measured values for several tests performed by H. Zimmerman on unrestrained oxide fuel.[6]

Representative results of analysis of the thermionic concept are shown in Fig. 3. This figure shows the predicted deformation for a solid TFE to be used in the periphery and for an annular rod to be used at core center, for an emitter temperature of 1750 K. Other TFEs have inner holes of intermediate diameter, with predicted deformations between those shown in Fig. 3.

The results in Fig. 3 show significant difference between the solid and hollow pellet designs. These results clearly depend on correct modeling of UO_2 creep. Hence, the verification of ability to predict relevant test results as was reported earlier is quite important. These results suggest that an important option for optimizing thermionic fuel element lifetime in this design would be to redistribute central void from center to peripheral elements.

THERMOELECTRIC CONCEPT

The proposed thermoelectric fuel design was for 96% dense nitride fuel clad in 29 mil thick PWC-11 alloy (Nb-1%Zr-0.1% C) with a 5 mil thick tungsten liner. The pin was to be operated at a peak cladding temperature of 1400 K, and was not vented. It would be operated at a peak power of about 4.1 kW/ft to a peak burnup of ~4.9 a/o. The pin diameter was 0.413 in., with a 5 mil net radial gap between fuel and cladding.

No satisfactory code exists to analyze the performance of nitride fuel at this time. There is a LIFE-4 CN code,[3] but the nitride aspects of the code have long been neglected. We used LIFE-4 CN strictly as a heat transfer code. Brian Harbourne of General Electric identified a carbide fuel unrestrained swelling model developed by H. Zimmerman of KfK[4] that appears to correlate available nitride data, and developed a fission gas release correlation based primarily upon temperature gradient as a driving force. Using variations of these models,* we analyzed the performance manually. We first calculated fuel temperatures for contamination of plenum gas ranging from 0 to 100%, and for volumetric swelling ranging from 0 to ~9% (gap closure expected at about 8.7% $\Delta V/V$). Charts were prepared showing mean fuel temperature as a function of fission gas contamination with swelling as a parameter. Calculating in increments of 0.5 a/o burnup, we would assume a fuel temperature and calculate the swelling and fission gas release overall axial segments. We then determined fuel temperatures corresponding to the swelling and plenum gas contamination from the charts. The calculation was repeated until assumed and calculated temperatures agreed at each burnup increment. Subsequently, we mechanized the procedure. Mean fuel temperatures calculated by the mechanized method are shown in Fig. 4.

With this process and the modified gas release correlation, we estimated an overall fission gas release of 33%, about 1% creep strain due to plenum gas, and 1.9% strain due to fuel swelling.** To translate fuel swelling into $\Delta D/D$, we assumed isotropic swelling and that the fuel was too strong for the cladding to modify its behavior.

Using the same process and the <u>original</u> gas release correlation as proposed by Harbourne, we obtained 5% fission gas release and negligible creep strain with either Nb-1%Zr or PWC-11 cladding.

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*The fission gas release correlation was modified to be somewhat more conservative than the original correlation.

**Total strain should be considered the maximum of creep or fuel swelling strain, not the sum of the two.

CONCLUSIONS

As a result of our analyses of these two concepts, we conclude that:

1. Available oxide fuel models with modifications provide an acceptable means of evaluating oxide fuel systems for space applications;

2. A integrated fuel pin performance model is needed for nitride fuel pins;

3. Better understanding of fission gas release and swelling for nitride fuel is needed before detailed design of nitride fuel systems can proceed with confidence.

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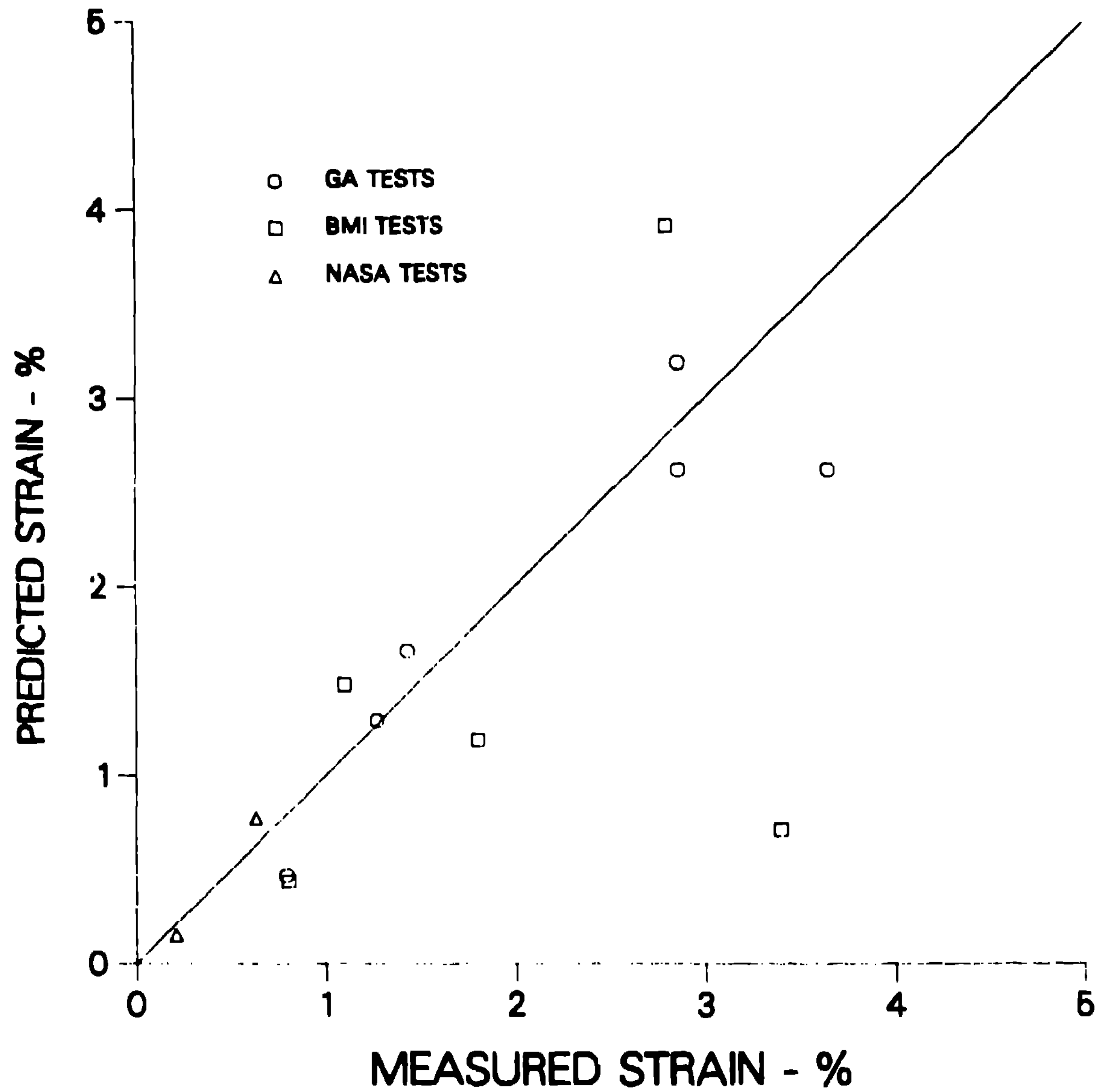

Fig. 1. Calculated cladding strain is compared with measured strain for several thermionic elements and other related tests.[2-5]

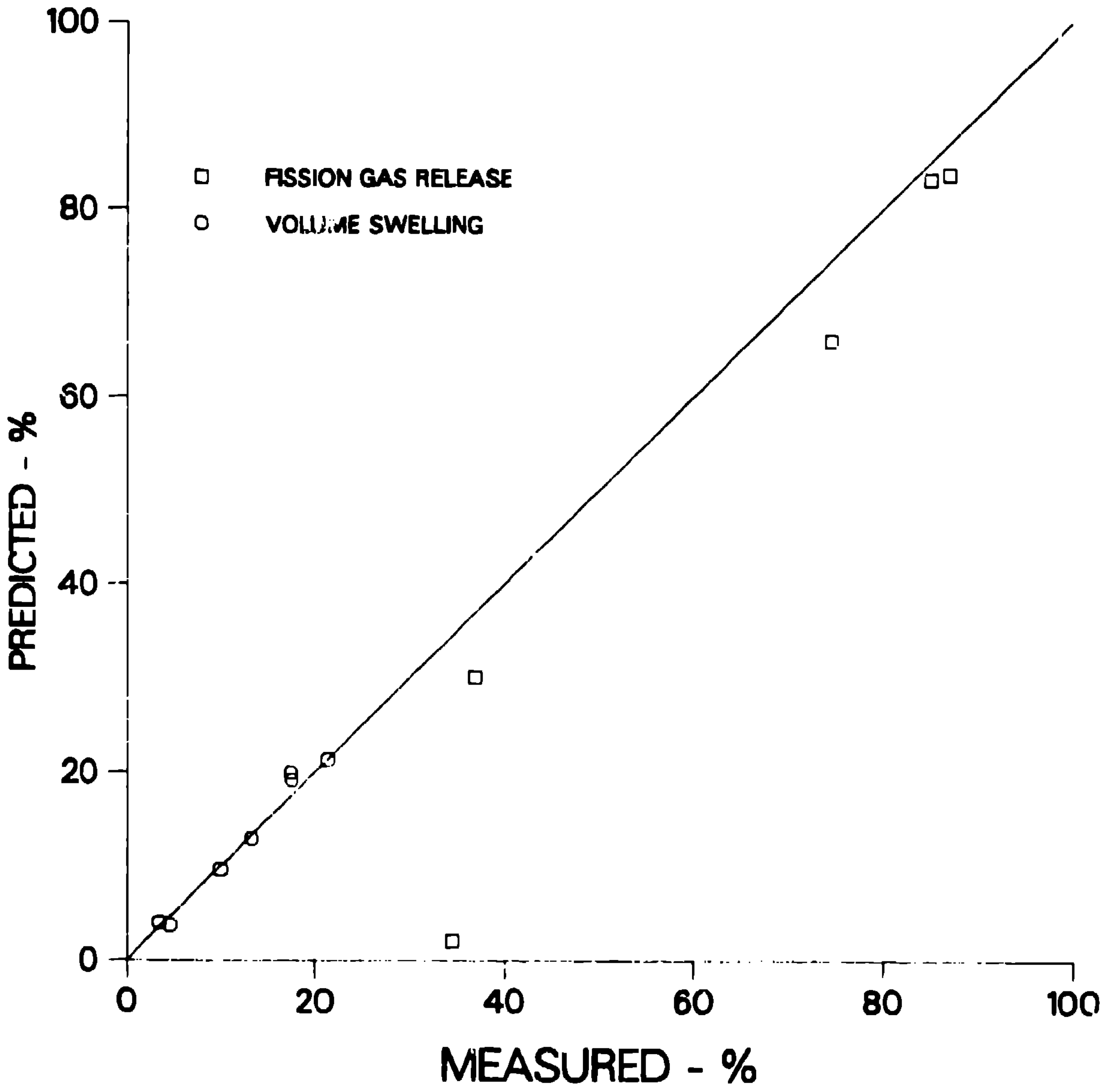

Fig. 2. Calculated results are compared with measured results for fission gas release and swelling for several unrestrained oxide tests conducted by H. Zimmerman of KfK.[6]

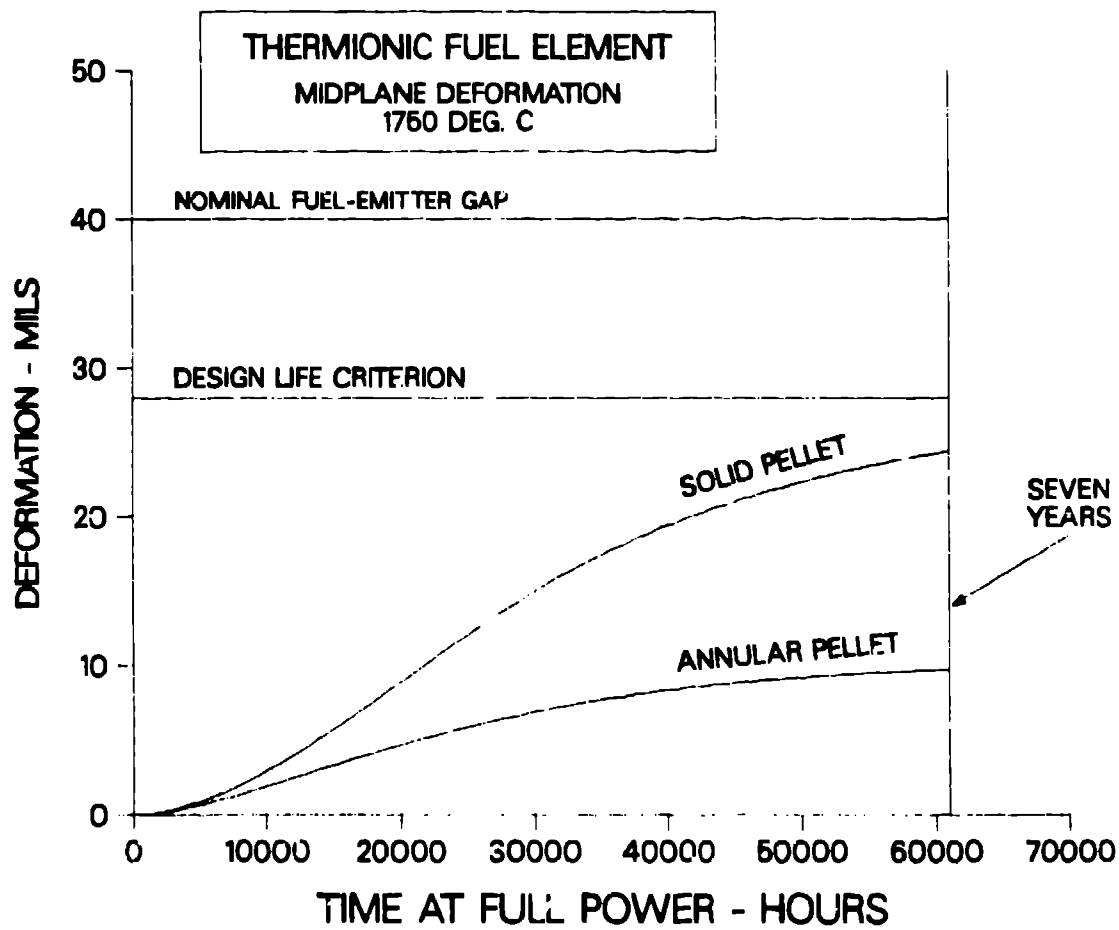

Fig. 3. Calculated axial midplane emitter deformations for core center (annular or pellet) and peripheral (solid pellet) thermionic fuel element proposed for an SP-100 proposed design.

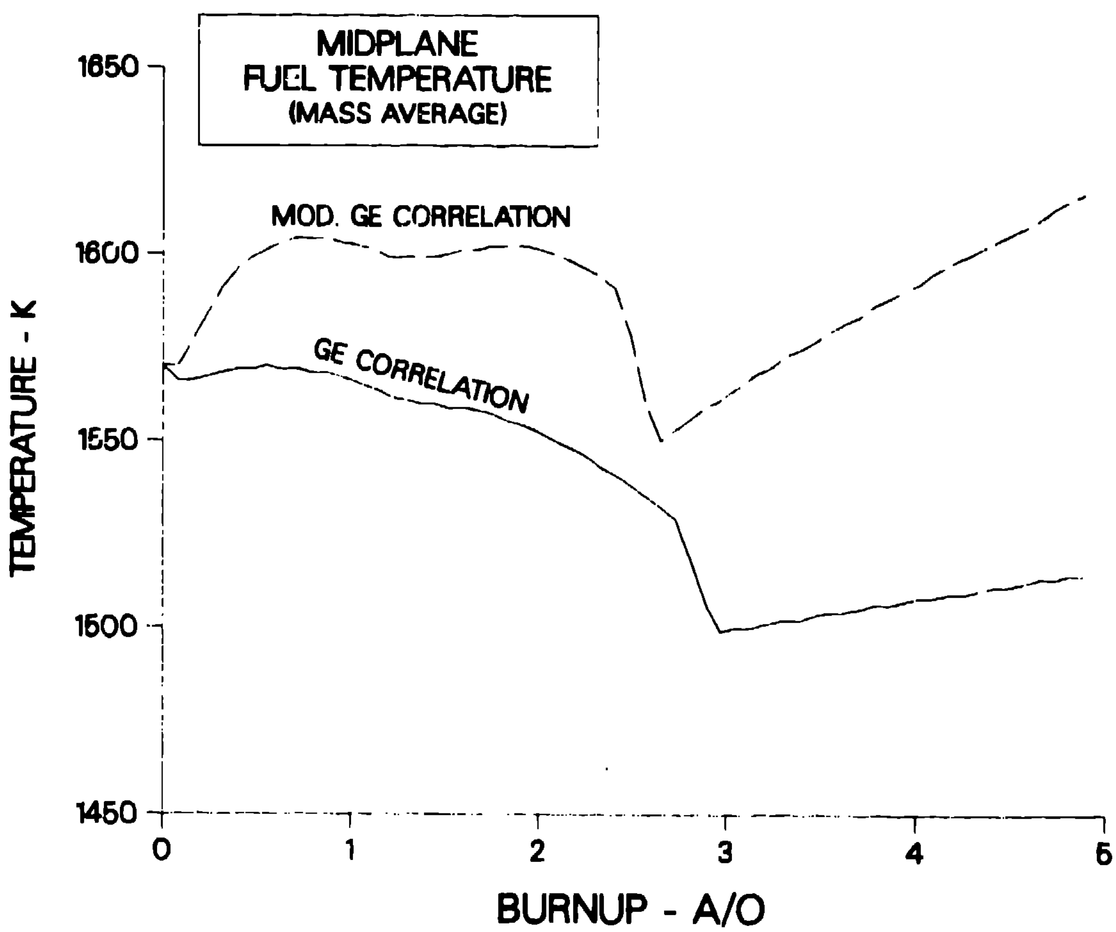

Fig. 4. Mass averaged axial midplane fuel temperatures are shown for the peak powered thermoelectric nitride fuel element, both for the original fission gas release correlation provided by General Electric and for the correlation as it was modified.